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Design and prototyping of a family of OLED luminaires for indoor environmental applications: results from the ODALINE project

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Abstract

Results of the project 'ODALINE' (OLED Devices Application in Luminaires for Interior and Exterior lighting) are presented. A team of academic and industrial partners worked together to design and manufacture a family of OLED luminaires. The project went through the following phases: i) analysis of the state-of-the-art of OLED technology; ii) identification of scenarios and application fields for OLED-based lighting systems and definition of requirements and performances expected for each scenario; iii) definition of the concept of new OLED lighting systems and development of their preliminary design; iv) executive design and manufacturing of some prototypes. After the identification of the most suitable OLED unit and of the application scenarios, the concept of the new luminaires was conceived: the luminaires rely on a suitable aggregation of a base module (consisting of an array of 6 OLED units, measuring 30 cm ∗ 20 cm) to provide systems with enhanced properties in terms of high efficiency, high quality light and flexibility as the luminaires can be combined to respond to different lighting tasks for indoor environmental applications. Final output of the research project was the manufacturing of three prototypes: a suspended luminaire (6 basic modules), a free-standing luminaire (4 basic modules) and a task lighting luminaire (1 module). The power supply system, consistently with the general concept, was developed for a single module rather than for the whole luminaire. Its architecture was conceived to allow the control of the luminaire (switching on/off, dimming) through the DALI digital protocol. Furthermore, some secondary optics were conceived and designed to concentrate the Lambertian light output and to increase the utilization factor of the flux.

Keywords: SSL; OLED luminaires for indoor spaces; ODALINE; Suspended luminaire; Free-standing luminaire; Task luminaire

Background

OLED (Organic Light Emitting Diode) is a flat light emitting technology, made by placing a series of organic thin films between two conductors. When electrical current is applied, a bright light is emitted [1]. Organic stack materials include emissive layers (EML), hole and electron injection layers (HIL, EIL), transport layers (HTL, ETL) and blocking layers (HBL, EBL) [2]. Through electron–hole recombination, a high-energy molecular state is formed (called *exciton*), which behaves like a single molecule with high energy and generates light after an exciton lifetime period. Organic stack materials can be polymeric (POLED) or small molecule (SMOLED) materials. As pointed out in a study from the US Department of Energy [3], “at present, most high performance lighting panels employ small molecule organics deposited using vapor deposition techniques. Polymer materials have not yet demonstrated the high efficiency and lifetime that is achieved in small molecules, but are being explored because they work well with flexible substrates, can be aligned to aid in light extraction, and may potentially lead to lower deposition costs as they are more amenable to solution processing”.

The research and development process for OLEDs has been delayed compared to what happened for LEDs: currently a limited number of OLED luminaires are available in the market and these are for particular applications or for demonstrative purposes only. The main reasons are mainly concerned, from the first experimental products, with the limited light output and the high cost of the overall manufacturing process, in particular with regard to the sizes of the modules. Presently, OLEDs can be hardly used as the primary source of lighting in a space. Based on manufacturers’ initial proposals, they should be used in conjunction with ambient lighting. For example, an OLED task light could be used, as the low brightness of OLEDs allows them to be placed close to the task surface without being uncomfortable to the user. In this regard, technologies for shaping the OLED light distribution may be required to improve light utilization.

The relatively broad line-width of red emission from OLEDs makes it difficult to achieve excellent color quality and high efficacy simultaneously. Nevertheless, over the last years an enhanced interest towards OLEDs has led to the development of new units characterized by higher luminous efficacy, longer life-spam, lower cost and better light and colour quality (warm light with different Correlated Colour Temperatures). According to two other studies carried out by the US Department of Energy [4, 5], the average cost of OLEDs, estimated equal to 500 $/klm in 2014 for an OLED panel will drop to 50 dollars/klm in 2015 and to 25 dollars /klm in 2020, whilst the luminous efficacy is expected to reach values as high as 135 lm/W in 2015 (being 45 lm/W in 2011 and 80 lm/W in 2014), with a feasible goal of 190 lm/W. The brightness is also expected to double its value in 2015 compared to the current performance. On the geometrical side, the sizes of OLED units, presently limited to 300 mm $*$ 100 mm (but 100 mm $*$ 100 mm square unites are typically manufactured) will be consolidated in 30 mm $*$ 30 mm square units in 2015. According to [5], from laboratory measurements, “Konica Minolta has shown a 15 cm^2 panel with an efficacy of 131 lm/W at 1000 cd/m^2 and 118 lm/W at 3000 cd/m^2, while Panasonic has successfully scaled their technology to an area of 25 cm^2, achieving efficacy of 112 lm/W at 1000 cd/m^2 and 98 lm/W at 3000 cd/m^2. Lumen maintenance (L50) for both panels is acceptable at 55,000 h for the Konica Minolta panel and over 100,000 h for the Panasonic panel when operated at 1000 cd/m^2”. According to what Ron Mertens reports in a website on OLED technologies [6], some analysts optimistically forecast that the OLED lighting market will reach 82 million in 2015 and $4.7 billion in 2020, while other analysts see a $200 million panel market in 2019 that will grow to $1.9 billion in 2025. Other analysts expect OLED to compete with LEDs in 2016.

Furthermore, it is worth stressing that the OLED emission spectrum is limited to the whole visible range, with neither UV nor IR energy release, which makes OLED compliant with the latest requirements in terms of control of Artificial Optical Radiations set by the European Directive 2006/25/CE [7], with regard to the spectral emission of light sources, their position and the exposure time for the users. Besides, OLEDs are 100 % recyclable and compliant with the RoHS directives [8]. As a result, some research projects have been recently carried out to develop high performance OLEDs and to promote their applications, such as the OLED100.eu [9] and the IMOLA [10], both funded by the European Union within the 7th Framework Programme, and new products have been recently released, which are suitable not only for particular applications such as decorative lighting, but for indoor lighting applications, with regard to residential and non-residential buildings (hospitality, museums, offices). Another example is the project is Flex-O-Fab, which is promoting the development of a robust supply chain for the manufacture of OLEDs on flexible substrates, using either roll-to-roll or sheet-to-sheet processing [11].

Within this context, this paper describes the results from the ODALINE project: this was aimed at designing and manufacturing a family of prototypes of OLED luminaires (a suspended, a free-standing and a task lighting luminaire) through a suitable, effective and modular aggregation of a base module. These OLED luminaires are intended for use in indoor spaces, able to respond to a variety of typical illuminance requirements.

Method

ODALINE (Oled Devices Application in Luminaires for Interior and Exterior lighting) is a 2-years research project funded by the Regione Piemonte, Italy, in the frame of the 'European Fund for Regional Development', and managed by the Pole of Innovation Polight at the Turin-based Environment Park. The project was carried out from September 2011 to January 2014.

The Research Team consisted of both academic and industrial partners, namely:

- Politecnico di Torino–Department of Energy as scientific and administrative coordinator
- ILTI Luce (belonging to Philips group), a company which deals with designing and manufacturing of luminaires
- SEDIS Light Technology, a company which deals with planning of optical systems for lighting instruments, with manufacturing instruments for photometric laboratories and with measuring photometric properties of lamps and luminaires
- ASTEL, a company which deals with designing and manufacturing of mechanical and electronic components.

Taking advantage of the features of OLEDs, the project was aimed at designing and manufacturing a family of innovative luminaires, with high standards with regard to:

- performances, in terms of global energy efficiency of the systems
- quality of the light output, in terms of control of glare perceived by the users and colour properties of the emitted light (Colour Rendering Index and Correlated Colour Temperature)
- flexibility of the lighting systems, in terms of capability of responding to different lighting requirements of a variety of indoor environmental applications (residential and non-residential).

Several aspects such as environmental lighting requirements, formal, expressive and constructive issues, control solutions and secondary optics for light redirection were considered during the design process.

In more detail, the project was developed through the following stages:

i) *analysis of the state-of-the-art of OLED technology*: following a market analysis, some OLED typologies potentially useful for the development of the ODALINE luminaires were identified and purchased. These OLED panels were characterized in terms of photometric, chromatic and electric performances through laboratory measurements. The following quantities were measured or calculated from measured data: absorbed electric power, lumen output, luminous efficacy, luminous intensity and photometric curve, chromatic coordinates, Colour Rendering Index, Correlated Colour Temperature, spectral emission (including UV and IR content), surface temperature and luminance distribution of the luminous surface.
Beside the characterization of the OLED units, the market research was also addressed towards existing OLED luminaires: in this regard, a substantial lack of families of products able to meet different requirements for indoor purposes through coordinated, flexible and modular solutions was observed
ii) *identification of scenarios and application fields for OLED-based lighting systems and definition of the corresponding required performances*: based on performances of OLED units measured in the previous stage, an analysis of possible scenarios for which OLED luminaires could be suitable was carried out. Different building types and usages were investigated in terms of their users, activities, requirements and expected performances; particular attention was paid to lighting performances related to health and comfort for the occupants, to safety, protection and management costs (concerned with energy and maintenance), to control functions and to the formal look of the final products. In more detail, the following classes of requirements were analyzed for each scenario, according to the Italian Tehcnical Standard UNI 11277:2008 [12]:
   - safety, in terms of electrical, thermal and mechanical protection for both the system itself and for users
   - wellbeing, in terms of visual/thermal comfort for users and of generating healthy conditions for users
   - conservation, in terms of preservation of exposed materials (in particular for Museums application scenarios)
   - usability, in terms of allowing an easy and flexible management of the system
   - aesthetical look, in terms of aspect of the system and of its integration in a real context
   - management, in terms of allowing a reduction in both the operating costs and in the energy consumed
   - possible integration of the system with other mechanical or HVAC systems
   - environmental sustainability (ecocompatibility), through a low impact on the environment in terms of reduced energy consumption and life cycle of the system.

After the identification of the various scenarios, a series of simulations were performed using a lighting simulation software (Dialux) to verify the lighting performances which could be obtained through the OLED aggregations with respect to the lighting requirements identified for each scenario.

iii) *definition of the concept of new OLED lighting systems and development of their preliminary design*: the fundamental requirements of the luminaire design were based on the concept of modularity and flexibility; the aim of the project was in fact to design, rather than a single OLED luminaire, a family of luminaires, to be obtained through a suitable aggregation of a basic module. Within the ODALINE project, three different possible aggregations were investigated to obtain a suspended, a free-standing and task lighting luminaire. These luminaires were intended to be used separately or in combination to meet different lighting requirements for different typologies of activities. As for the luminaire, the formal solutions, the components, the materials, the supporting structure and the constructions details were defined. As for the light output, some secondary optic systems were modelled and simulated, to concentrate the Lambertian emitted flux and to increase the utilization factor of the flux for those applications where a limited emission angle is required. As for the power supply system, consistently with the general concept, this was developed for a single module rather than for the whole luminaire. Furthermore, the system was conceived to allow the control of the luminaire (switching on/off, dimming) through the DALI digital protocol.

iv) *development of the executive design and manufacturing of different prototypes*: the prototypes of a suspended luminaire, a free-standing and a task light luminaire were designed and manufactured

v) *laboratory performance characterization of the prototypes*: energy, photometric and chromatic characteristics of the three prototypes were measured in laboratory using the same procedures and instruments as already used to characterize the single OLED units (stage *i*)).

Results and discussion

In the following subsections, the main results which were found for the steps *i*) through *v*) (design and manufacturing of OLED prototypes) are presented.

Analysis of the state-of-the-art of OLED technology

The research of OLED units existing market was carried out in the period September 2011–June 2012Different OLED units were considered from different manufactures, so as to account for different technologies, sizes and performances. After a first selection, the following OLED units were eventually purchased and tested:

- Osram Orbeos CMW-031 and RMW-046
- Philips Lumiblade GL350 BI STAN
- LGChem LG6S2
- Lumiotec P05C and P06L
- Verbatim Velve RGB

Figure 1 summarizes the main performances which were measured for some of the OLED units tested.

At the end of this stage, two OLED were selected for further analyses and comparisons in next stages:

- Philips Lumiblade GL350, which performed a low luminous efficacy (16.1 lm/W) but a high light output and brightness (3284 cd/m^2)

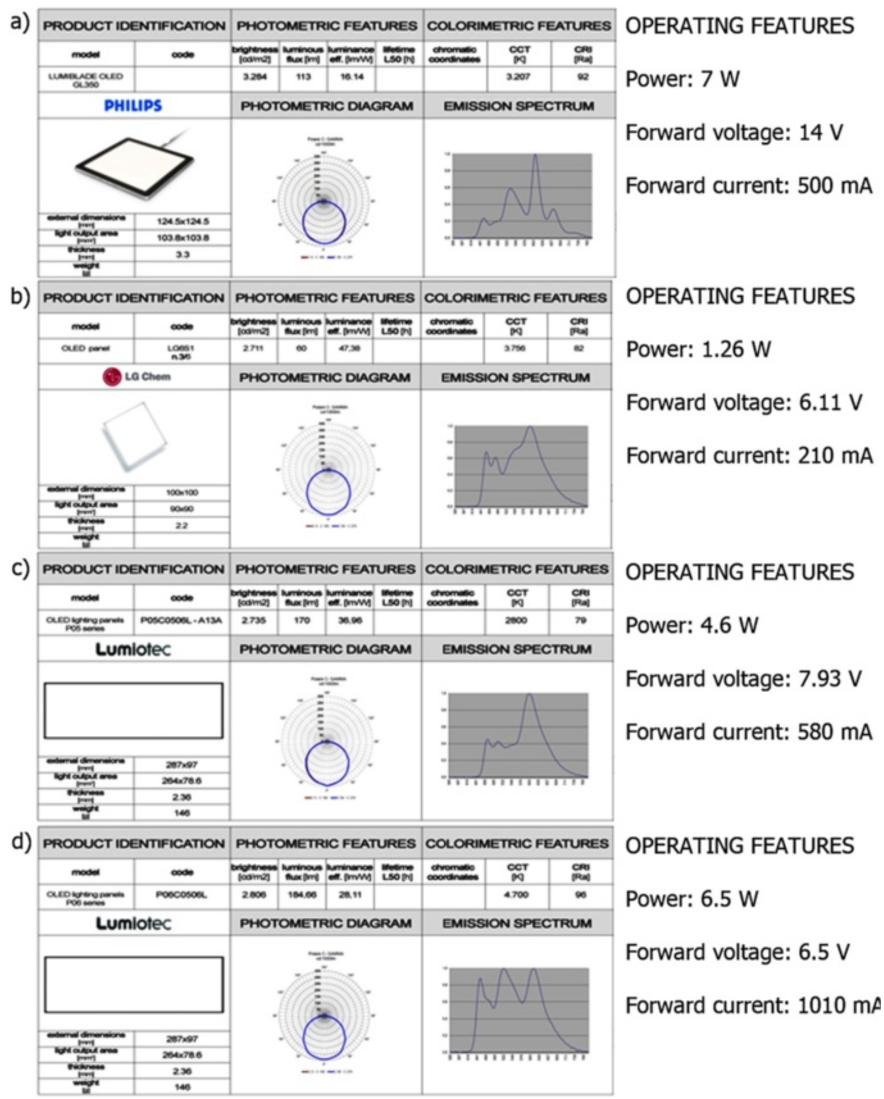


Fig. 1 Performances measured for some of the OLED units which were tested: **a** Philips Lumiblade GL350; **b** LGChem LG6S1; **c** Lumiotec P05 Series; **d** Lumiotec P06 Series

- LGChem LG6S1, which performed a high luminous efficacy (47.4 lm/W) but a low light output and brightness (2711 cd/m^2).

Scenarios and applications fields for OLED luminaires and definition of requirements and performances of OLED luminaires

For each scenario which was identified as potential application field of OLED luminaires, a list of requirements OLED luminaires are expected to meet was defined. Some synoptic tables were then prepared to summarize and compare the different requirements/performances for the different scenarios. These are shown in Fig. 2.

The following scenarios were found to be the most promising application sectors for a new series of OLED luminaires:

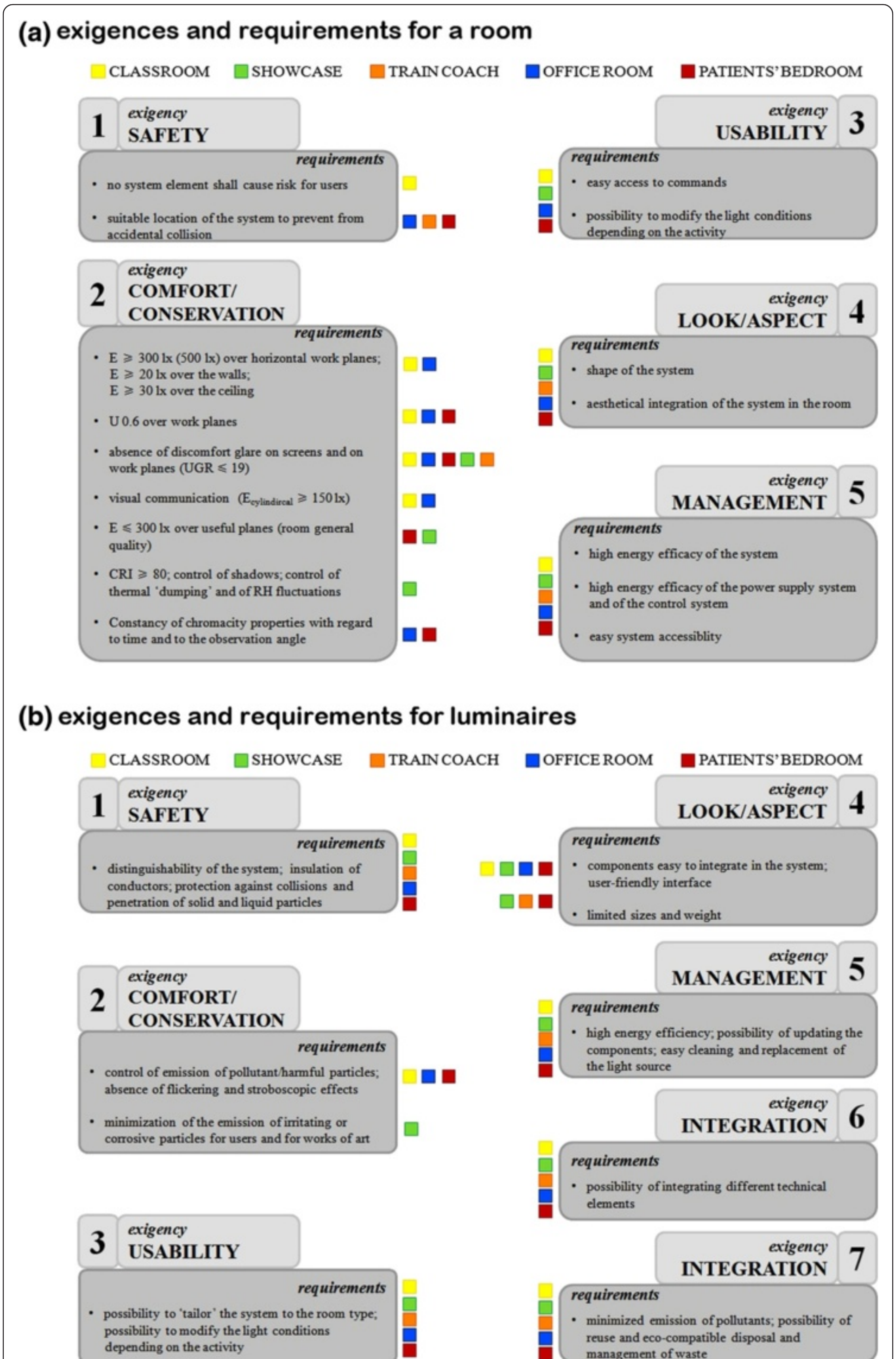


Fig. 2 List of exigencies and requirements defined for the environment (**a**) and luminaires (**b**)

- residential spaces
- office rooms (cellular, open-plan, conference rooms)
- hospitality
- health care facilities

- exhibitions (showcases)
- transportation (train coaches).

For each scenario, a list of requirements and expected performances was defined, according to the lighting requirements prescribed by the European Standard EN 12464-1:2011 [13]: this was done with reference to both the space in which a given activity is carried out by occupants (in an office, in a hospital bedroom or in a train coach, etc.) and to the luminaire itself. For the particular case of train coaches, due to the lack of a specific European Standard, the requirements expressed in [13] were assumed as reference, with regard to a work plane for reading/writing activities or for working on a computer and to the corridor. Based on the requirements, an appropriate aggregation of OLED units was studied to satisfy the class of performances afore described.

Table 1 summarizes the results of the lighting simulations which were run for the most suitable scenarios to verify which aggregation of OLED units was able to meet the standard requirements. Simulations were performed for the two OLED units selected at the end of the previous stage. For each OLED module, the photometric curve and the luminous efficacy which were measured during stage *i*) were used for simulations.

Concept for the OLED luminaires

Following up the results from the comparative analysis of different existing OLED units–stage *i*)–as well as the results from simulations–stage *ii*) -, the OLED model LG6S1, manufactured by LGChem, was selected as the most suitable for the ODALINE project: this is a 100 mm ∗ 100 mm square unit (thickness: 1.9 mm) and the data reported in the datasheet state a luminous efficacy of 60 lm/W, a CRI above 80, a CCT of 3700 K and a life spam between 15,000 and 20,000 h. The laboratory measurements showed that the actual luminous efficacy was lower than the catalogue value: a value of 47.4 lm/W was measured.

Based on the results of the previous stages of the project, an optimal aggregation of OLED units was defined: considering that, as shown through the analysis of the possible applications in different types of rooms, the luminaires needed to guarantee the lighting performances in different scenarios have many characteristics in common, resulting different mainly for the global quantity of light output to be provided, it was decided to create a basic module. This was an aggregation of OLED units, to be further composed to create different kinds of luminaires. Different aggregation of OLED units were explored and compared: in the end, the most optimal aggregation was an array of 6 OLED units (3∗2 units, total size: 30 cm ∗ 20 cm) as this allowed the most effective combination into luminaires, from both mechanical and photometric point of view. Subsequently, the preliminary project of the following three luminaires was defined:

- suspended luminaire, consisting of the aggregation of 6 basic modules; from the various simulations, an optimal mounting height of 2.3 m above the floor was defined
- free-standing luminaire, consisting of the aggregation of 4 basic modules; from the various simulations, an optimal mounting height of 1.85 m above the floor was defined
- task-light, consisting of the basic module itself.

Table 1 Results of Dialux simulations for three of the different scenarios which were analyzed: a cellular office, a health care bedroom and a train coach

Lighting system	# of OLEDs/ luminaire	# of luminaires	Total area[a] [cm^2]	h_m [m]	LPD [W/m^2]	Visual task area		Room area[b]	
						E_m [lux]	U [–]	E_m [lux]	U [–]
Cellular office (15 m^2)									
Ambient lighting (downlight suspended luminaires)									
OLED Philips	21	3	9.765	2.2	29.3	512	0.75	421	0.47
OLED LGChem	40	3	12.000	2.2	11.2	508	0.76	460	0.44
Light Field LED Zumtobel[c]	/	2	7.688	2.2	5.9	500	0.57	553	0.27
Ambient lighting (downlight suspended luminaires) + downlight free standing luminaire for the work plane									
OLED Philips	16 (susp.) +9 (stand)	3 + 1	3.875	2.2 (susp.) 1.7 (stand)	26.5	531 (piant.183)	0.58	386	0.49
OLED LGChem	16 (susp.) +9 (stand)	3 + 1	9.600	2.2 (susp.) 1.7 (stand)	8.95	510 (piant.175)	0.63	391	0.4
Free standing luminaire for the work plane (downlight OLED/uplight LED)									
OLED Philips		20 OLED	3100 (OLED)	1.7	13.3	488	0.35	232	0.28
OLED LGChem		25 OLED		1.7	5.5	352	0.37	173	0.34
Hospital bedroom (patients' room)									
Bedhead with downlight luminaires									
OLED Philips	6	1	930	1.5	1.7	191	0.7		
OLED LGChem	6	1	600	1.5	0.7	103	0.7		
Bedhead with downlight OLED/uplight LED luminaires									
OLED Philips	6	2		1.5 OLED 1.7 LED	7.25	540	0.9		
OLED LGChem	6	2		1.5 OLED 1.7 LED	6	453	0.9		

Table 1 Results of Dialux simulations for three of the different scenarios which were analyzed: a cellular office, a health care bedroom and a train coach *(Continued)*

BELIA Zumtobel (LED)[d]	/	1	2.726 (tot)	1.5 OLED 1.7 FLUO	6	401	0.9		
Train coach									
Ambient lighting of a modular bay (4 facing seats + corridor)									
OLED Philips	19	/	2.945	2	19 ca	388	0.7	306	0.47
OLED LGChem	19	/	1.900	2	3.8	197	0.66	64	0.06

h_m mounting height [m], *LDP* Lighting Power Density [W/m^2]
[a]total luminous area for a single luminaire
[b]room area minus a peripheral stripe having a depth of 50 cm
[c]for comparative purposes, a simulation with a suspended downlight luminaire by Zumtobel, equipped with LEDs was also performed
[d]for comparative purposes, a simulation with a downlight/uplight bedhead by Zumtobel, equipped with 2 ∗ 54 W fluorescent tubes, was also performed

The different aggregations which were defined for the basic module and for the three luminaires are shown in Fig. 3. Different combinations of the designed OLED luminaires can be fruitfully used to satisfy the lighting requirements (illuminance and uniformity values) over the work plane in different indoor environmental applications: for instance, for an office room, three suspended luminaires or a combination of three suspended luminaires and one task lighting or a combination of two suspended luminaires and one free-standing luminaire are able to meet the standard requirements. In this way, different solutions can be made available for the same environment.

Beside the basic module for the family of OLED luminaires and the definition of modules aggregation for luminaires to be used in scenarios like offices or similar, two more OLED luminaires solutions were explored, for specific applications: the first one was conceived as a bedhead in a patients' room in health care facilities, with the aim to evenly light the reading area of the patient's bed. The second one was conceived for train coaches, to light the area of a table and four seats for passengers as

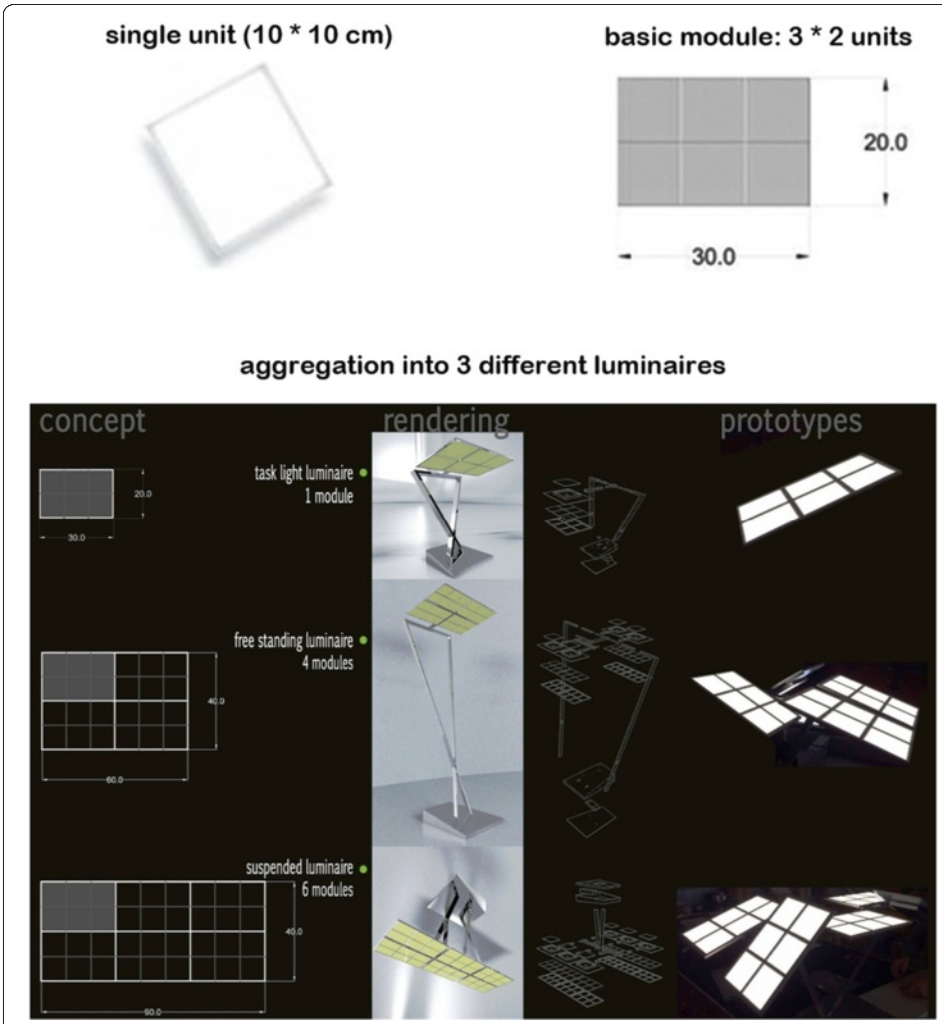


Fig. 3 Different aggregation of the OLED module to create 3 different luminaires. A ceiling-suspended, a free-standing and a task lighting were created

well as the corridor. For both applications, the OLED luminaire consisted of a 'strip' of OLED, rather than a 3∗2 OLED array, to better fit the limited space which is available in a bedhead or in a train coach (where a continuous line of luminaires is typically installed).

The preliminary design dealt with different aspects:

- *design of the optics*: the numerical simulations showed that for some applications (for instance the bed head lighting for patients' rooms) better performances would be guaranteed by modifying the Lambertian distribution of the light output, which is an inherent characteristics of OLED sources, in order to concentrate the flux towards the work planes. In this regard, an innovative system to increase the efficacy of the OLED units through micro prismatic films was studied, analysing the appropriate materials and geometry through specific simulation tools. The photometric curve which was obtained is shown in Fig. 4: the visible transmittance of the micro prismatic films (which can be assumed as an efficiency of the optical system to concentrate the light output) was equal to 80 %.
- *design of the power supply and control system*: the concept of modularity of the project was implemented through the decision to associate the supply and control system to each OLED module. The control system was also conceived to be integrated with the components for functions such as switching on/off and photodimming through the digital protocol DALI: the management firmware was also designed. Each electric circuit was tested in operative conditions of temperature, supply and overloads. A particular effort was paid to keep the thickness of the supply/control unit to a minimum, so as to maintain the inherent character of OLEDs as thin light sources

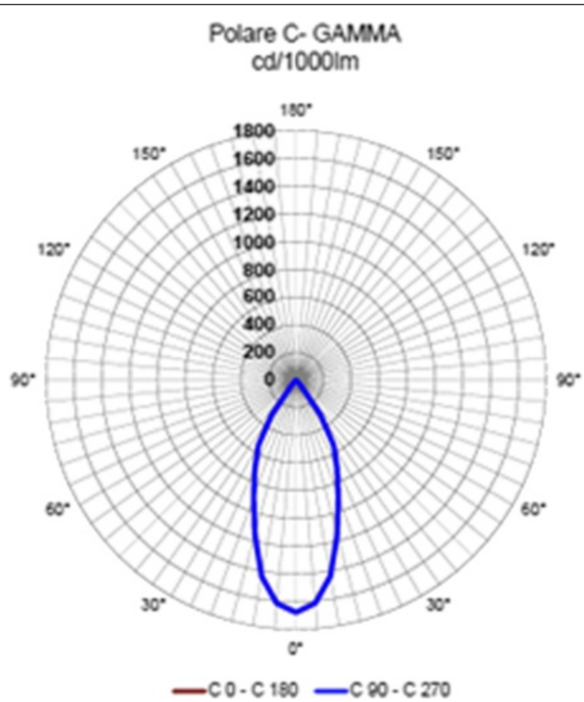


Fig. 4 Photometric curve of OLED units after the application of micro prismatic films

- *design of the resulting luminaire*: the aggregation of the basic modules needed to create the suspended, the free-standing and the task-light luminaire was coupled with the power supply into a package. A supporting system was designed to assembly the different components and to guarantee the mechanical resistance. It was also conceived to allow the OLED modules to be individually tilted. For the suspended luminaire, for instance, each module can allow a tilting of up to 180°: the user can hence decide the final 'look' of the luminaire, as well as its actual photometric distribution of the light output (direct, indirect, or any intermediate combinations).

Performances of the prototypes

The preliminary design was then turned into an executive design and three prototypes of the three conceived luminaires were actually built (Fig. 5) and characterized in terms of their performances.

Figure 6 summarizes the performances of the three prototypes as measured in laboratory. It was observed that the luminous efficacy values measured for the assembled prototypes were lower than what measured for the single OLED unit (relative decrement in the range 12.6–19.6 %). This is due to global efficacy of the power supply system which was actually achieved: the choice of installing a power system for each OLED module rather than having a general system for the whole luminaire resulted in a loss in terms of efficacy, but on the other hand was consistent with the modularity feature of the project, as the same concept can in principle be applied to any aggregation of luminaires. It is worth highlighting that the loss in the luminaire efficacy which was measured for OLED luminaires is in line with the data reported in [6], according to which a loss of 15 % was observed for an OLED luminaire compared to the efficacy of an OLED panel.

A new series of lighting simulation was then performed to quantify the consequent reduction of the illuminance values over the work planes for the different indoor environmental applications considered in the project, due to the reduction of the luminaires' luminous efficacies, and to verify if the standard requirements were still met. As an example, Fig. 7 show the results obtained for a typical cellular office in which three suspended luminaires are installed, while Fig. 8 shows the results for a health care patients' room (strip of 6 OLEDs integrated with an indirect fluorescent system) and Fig. 9 the results for a train coach.

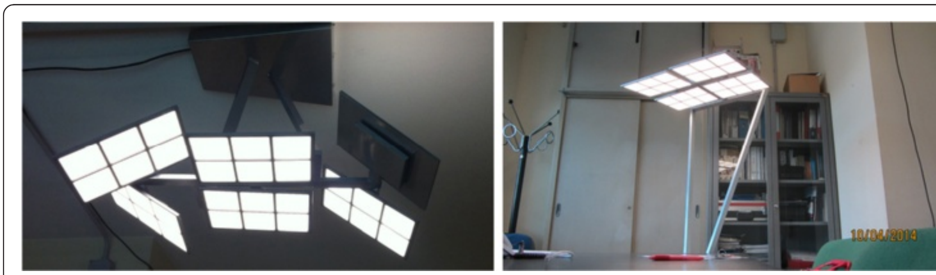


Fig. 5 Prototypes of the suspended luminaire (*left*) and of the free standing luminaire (*right*)

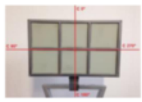
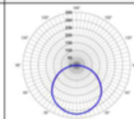
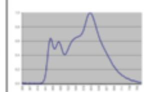
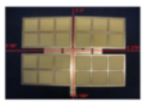
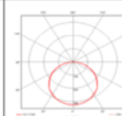
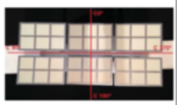
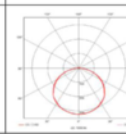
Prototype	Dimensions [mm]	Thickness [mm]	Luminous flux [lm]	Power [W]	Luminous efficacy [lm/W]	TCC [K]	Photometric diagram	Emission spectrum
	320x220	26	407	9,82	41,5	3.690		
	650x470	26	820	39,28	38,1	3.690		
	980x480	26	1.230	58,92	39,9	3.690		

Fig. 6 Summary of performances measured in laboratory on the luminaire prototypes. Note: measurements were taken in the absence of the secondary optics which was studied in the project

Discussion

The main features of the developed luminaires are expected to be the high efficacy, which makes them comparable with other lighting systems available in the market, the high quality of the light output, uniform and glare-free, and the possibility of integration with control systems using the DALI digital protocol. The prototypes showed an energy performance lower than expected: the luminous efficacy which was measured in laboratory for an OLED unit was lower than the value reported in the technical datasheet (47.4 lm/W versus 60 lm/W). Furthermore, the luminous efficacy of the final luminaires which were prototyped was even lower (a decrease in the range 12.6–19.6 %), due to the further losses concerned with the optical systems and the driver and the power supply efficiency. On the other hand, presently the luminous efficacy of the OLED units is rapidly increasing and is supposed to achieve values higher than 80 lm/W in

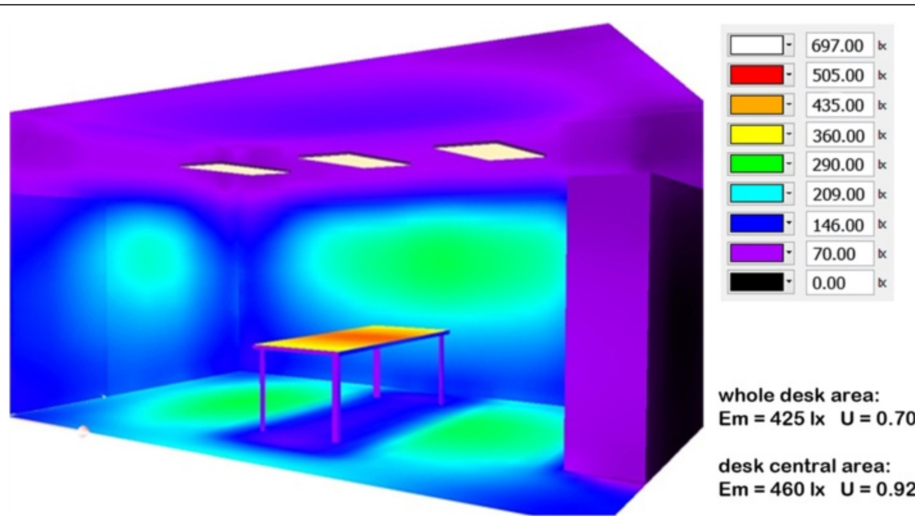


Fig. 7 Results of lighting simulations for a sample cellular office (5 m ∗ 3 m). Average illuminance over the desk (E_m) and uniformity (U) using the luminous efficacy value measured in laboratory for the prototype (η = 39.9 lm/W)

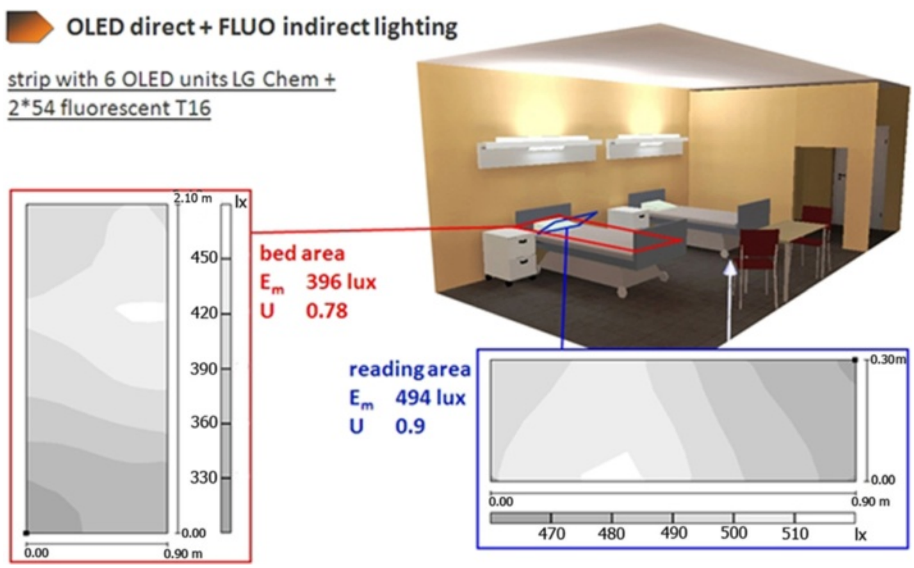


Fig. 8 Results of lighting simulations for a sample patients' room in a health care facility. Average illuminance (E_m) and uniformity (U) over the bed and over a reading area (luminous efficacy: η = 39.9 lm/W)

the next future: 135 lm/W are expected in 2015 but a feasible goal of 190 lm/W in the future [6]. As for the luminaires, an increment in the luminous efficacy from 50 lm/W measured in 2013 to a target of 130 lm/W in 2020 is expected, with a subsequent further increment up to 162 lm/W [6].

For the case of LGChem OLEDs, it is worth stressing that during the development of the ODALINE project, from the initial OLED characterization to the prototyping of OLED luminaires, the luminous efficacy was increased by one third: units with a luminous efficacy of 80 lm/W (data taken from the manufacturer technical datasheet) have been recently released, with a CTT of 3000 K. More models with the same efficacy and other sizes and CTT are expected to be released within 2015. These new units can be installed in the luminaires frame thus providing higher illuminance levels over the work planes or

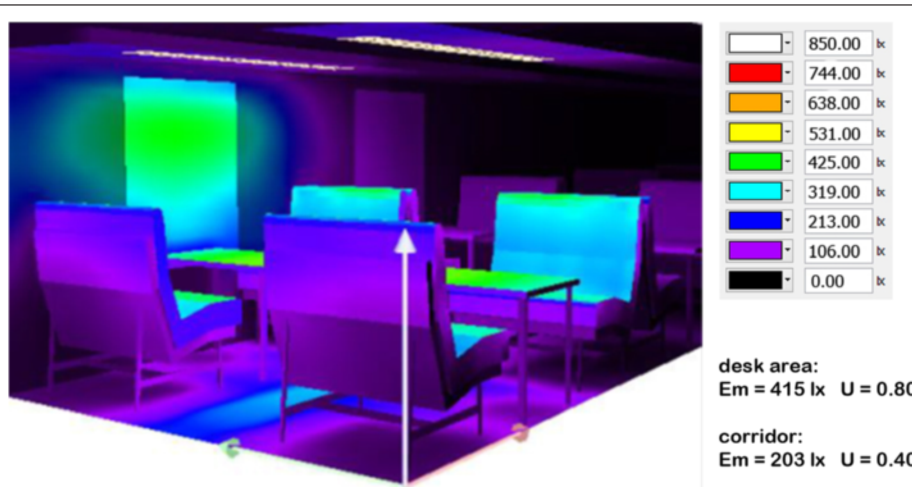


Fig. 9 Results of lighting simulations for a sample train coach. Average illuminance (E_m) and uniformity (U) over the table and over the corridor (luminous efficacy: η = 39.9 lm/W)

allowing different combinations of luminaires to be used with a reduction of the installed power density.

Conclusions

This paper presented the ODALINE project, a research project whose main output was concerned with the development and manufacturing of a family of OLED luminaires based on concepts of modularity and flexibility. The research team worked through a multidisciplinary approach, which allowed addressing various aspects such as: lighting requirements; formal, geometrical and constructive features; photometric properties through primary and secondary optical systems purposely designed; power supply performances, also for the control of the light output. Basically, a single OLED unit (OLED model LG6S1, manufactured by LGChem) was selected for the project and aggregated so as to create a basic module (consisting of an array of 6 units). Further aggregations of the basic module allowed creating a suspended luminaire (6 modules), a free-standing luminaire (4 modules) and a task-light (1 module). These luminaires are suitable for different indoor applications with are characterized by different lighting requirements: they can be combined in different ways to guarantee the minimum illuminance and uniformity values over the considered work planes. The application to a number of spaces (conference and office rooms, train coaches, healthcare rooms) was explored through a set of Dialux simulations.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
AP was the scientific coordinator of the research project; she conceived the project (together with CA) and supervised all the research stages. VRMLV wrote the manuscript, performed some simulations, elaborated the results obtained from simulations and measurements and participated in all discussions. CA conceived the project (together with AP) and supervised all the phases of the research, providing discussions on the methodology and on the results obtained. SF carried out most of the research on products, performed most of simulations and participated in measurement campaigns (with GP). GP carried out the market analysis of existing OLED and participated in measurement campaigns (with SF). All authors read and approved the final manuscript.

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